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Streamflow droughts assessment in Kurdistan Province, Iran

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ABSTRACT

In this paper, we analyzed the streamflow droughts based on the Percent of Normal Index (PNI) and clustering approaches in the Kurdistan Province, Iran, over the 1981-2010. The Kolmogorov-Smirnov (K-S) test was considered for streamflow time series and the results of K-S test indicated that streamflow time series did follow the normal distribution at the 0.05 significance level. Generally, the results showed that mostly streamflow droughts have been commenced since 1997 and also in most of the stations the extreme streamflow droughts occurred in 1997-2001. Furthermore, the number of drought events in each station showed that the extreme streamflow drought status in the Shilan station was the highest number with value 12, while the Tunnel Chehelgazi showed the lowest extreme drought status with value 4. Meanwhile, we used clustering approaches in order to explore homogeneities area which suffered from streamflow droughts. We selected two different clusters. So that, 5 stations out of 6 stations were classified in cluster 1 having the same situation in most years. The Shilan station had the specific conditions compared with other stations and classified in cluster 2. As a result, the clustering analysis was able to explore homogenous areas suffered from the same streamflow droughts. Therefore, the results of this work showed that the study area suffered from streamflow drought events over the three last decades, especially in last 14 years which can lead to many impacts on environment and ecosystems.

Key words: Streamflow, Clustering, Droughts, Kurdistan Province.

INTRODUCTION

Drought as one of the important environmental disasters occurs in all climates. It is a recurrent extreme climate event which strongly affects each components of the natural environment and human lives and in comparison with other, is a "creeping disaster" (Madadgar & Moradkhani 2013). According to Mishra & Singh (2010), as a natural hazard, drought is best characterized by multiple meteorological and hydrological variables and an understanding of the relationships between these two sets of variables is essential to develop measures for mitigating the impacts of drought events. Drought impacts can be defined both surface and groundwater resources and lead to reduced water supply, deteriorated water quality, crop failure, reduced rangeland productivity, diminished power generation, disturbed riparian habitats and suspended recreation activities, as well as affect a host of economic and social activities (Riebsame *et al.* 1991). However, drought is very important issue mainly due to its direct and indirect impacts. Several researchers suggested that there is not a universal definition of drought, but it can be defined with different disciplinary perspectives called meteorological, agricultural , hydrological and socioeconomic droughts (Yang 2010).

The hydrological drought is defined by deficit in streamflow series in the rivers. Several studies on hydrological drought were done throughout the world include: Wilhite & Glantz (1985), McKee *et al.* (1993), Morid *et al.* (2006), Paulo & Pereira (2007), Mishra & Singh (2010), Khalili *et al.* (2011), Tabari *et al.* (2012) and Madadgar & Moradkhani (2013). Zaidman *et al.* (2001) investigated spatial and temporal streamflow droughts in Europe in the last fourteen years and suggested that the worst streamflow droughts occurred in Northern France and Southern England. Khalili *et al.* (2011) applied the SPI and RDI indices in different climate zones of Iran, indicating that the RDI by utilizing the ETo can be very sensitive to climatic variability. Percent of Normal Index (PNI) for the streamflow drought severity analyzing in Northwest Iran were used by Nikbakht *et al.* (2012). They found that the worst streamflow droughts at almost all the stations occurred in 1999–2000 and 2000–2001 and also indicated that the streamflow drought severity increased during the last 34 years. Tigkas *et al.* (2012) assessed drought and climatic change impact on the streamflow in small watersheds in Greece showed that the anticipated streamflow change can be directly linked to the hydrological and meteorological droughts levels. It is important to inform policy makers on the drought causes, its impacts, several adaptation responses and possible mitigation measures perceived at local levels in order to decline human suffering (Bhattacharyya *et al.* 2004). The main objectives of this study are streamflow droughts assessment based on the PNI and then classifying the PNI series to different clusters. Finally, the impacts of streamflow droughts on the environment were discussed.

Study area and data

The study area is Kurdistan Province, situated at the western border of Iran. Its surface area is about 28817 square kilometers and its climatic behavior is approximately similar to mountainous areas.

Noteworthy, the winter in this region is cold and rainy, while the summer is warm and dry. Kurdistan Province has some important rivers supplying the water demands of its most parts. However, this region is more sensitive to droughts especially hydrological droughts. In this research, monthly streamflow series were collected from six hydrometric stations for period of 1981 to 2010 (Fig. 1).

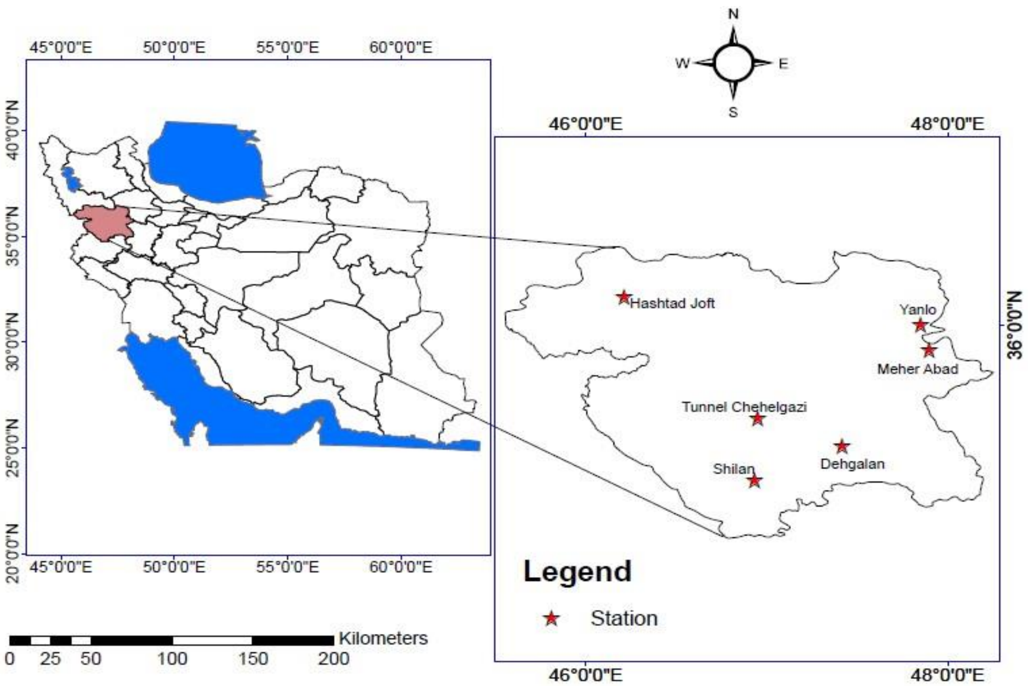

Fig. 1. Spatial distribution of hydrometric stations in the study area.

MATERIALS AND METHODS

Percent of Normal Index

In this study, the Percent of Normal Index (PNI) was used because its calculation is simple, by definition, and is easy to understand by a general audience (Smakhtin & Hughes 2004).

The PNI procedure mostly was used for meteorological drought, but it can also be used to streamflow for computing streamflow drought. This index is defined by dividing the actual streamflow (Si) by the normal streamflow ($\overline{S}$) and multiplying by 100 (Willeke *et al.* 1994). It is calculated by the following equation:

$$\mathrm{PNI} = \frac{Si}{\overline{S}} \times 100 \qquad (1)$$

In which, Si is the streamflow time series and $\overline{S}$ is the average of long-term streamflow series over the period. The different states are defined through the criteria of Table 1.

Table 1. Definition of states of hydrological drought based on the PNI.

State	Criterion	Description
0	PNI > 80	Normal
1	70 ≥ PNI < 80	Slight drought
2	55 ≥ PNI < 70	Moderate drought
3	40 ≥ PNI < 55	Severe drought
4	PNI < 40	Extreme drought

Clustering approaches

In this section, the clustering approaches were considered to explore the homogeneous areas suffered from the hydrological droughts. This method is able to classify several PNI series in the different clusters. The hierarchical clustering were selected which identifies relatively homogeneous groups of variables using an algorithm that considers each variable in a separate cluster and combines clusters until one is left (Stahl & Demuth 1999). Here, the hierarchical clustering was considered and the Ward, algorithm and squared Euclidean metric were selected. Then the normalized PNI series were classified based on the dendrograms.

RESULTS AND DISCUSSION

Sometimes streamflow time series do not follow normal distribution and mean or average of series may be not the same median streamflow series for using the PNI. Thus, initially it is important to analysis normality in streamflow series before calculating the hydrological drought index. Therefore, the Kolmogorov-Smirnov (K-S) test was considered for streamflow time series (Fig. 2). The outputs of K-S test showed that the highest p-value (0.72) was found in Mehr Abad station whereas the lowest p-value (0.09) detected in Shilan station. Therefore, the results of K-S test indicated that streamflow time series did follow the normal distribution at the 0.05 significance level.

The results of PNI for streamflow time - series in the study area over the 1981-2010 period depicted in Fig. 3. Generally, the results showed that most of streamflow droughts have been commenced since 1997 and also in the most stations the extreme streamflow droughts occurred in 1997 to 2001. Furthermore, streamflow time - series were in normal category before 1997. Between hydrometric stations, the Shilan stations suffered from streamflow droughts having the worst drought status more than other stations. For better understanding of the frequent occurrences of streamflow drought status, the number of drought events at each station is given in Table 2. It is evident that in the extreme streamflow drought status, Shilan station had the highest number with value 12, while Tunnel Chehelgazi showed the lowest extreme drought status with value 4. In addition, these stations were the same with the extreme drought category in the total droughts experiences. In contrast, in the severe drought category the Dehgalan and Yanlo stations had the highest and the lowest number of drought events, respectively. In accordance with this study, Nikbakht *et al.* (2012) found that the worst streamflow droughts at almost all the stations occurred in 1999–2000 and 2000–2001 in the Northwest Iran. The 1999 drought made the most destroying to agriculture and water resources of Iran, accelerating movement of people from rural to urban areas (Yazdani & Haghsheno 2008).

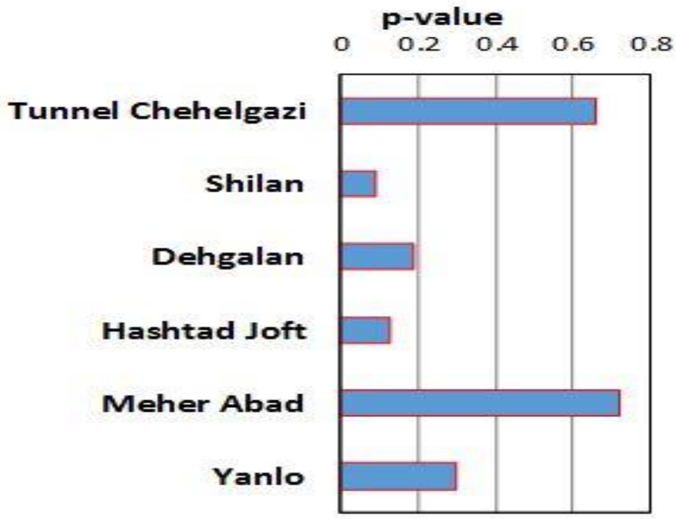

Fig. 2. The results of K-S test for streamflow time - series over 1981-2010.

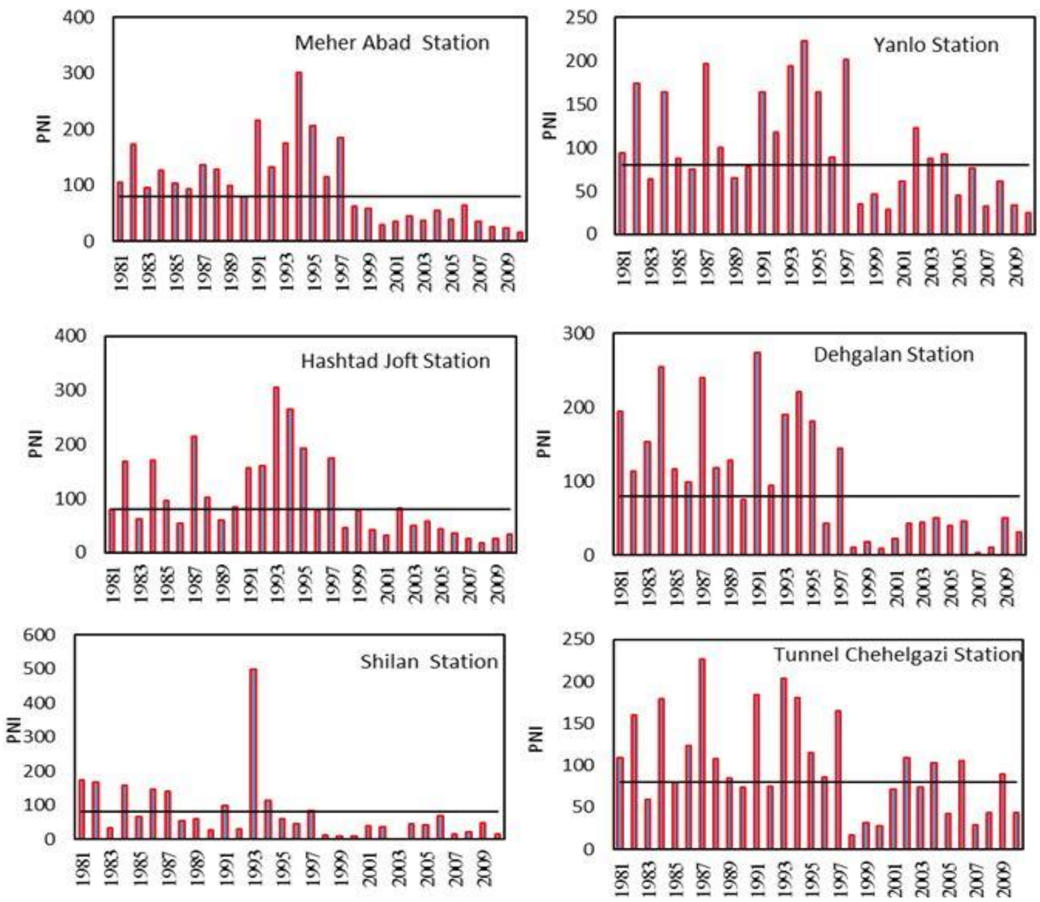

Fig. 3. The PNI series for streamflow series over 1981-2010 period (The black line indicates boundary of normal and drought status).

In this part, we used hierarchical clustering in order to explore homogeneous areas which suffered from streamflow droughts.

Based on the dendrograms, we selected two different clusters and the spatial distribution of clusters mapped in Fig. 4.

As showed, 5 stations out of 6 stations classified in cluster 1 having the same situation in most of the study period. The Shilan station, located at the southern part of the study area, showed relatively different results compared with the other stations and classified in cluster 2.

As shown in Fig. 5, the PNI series in each station were classified in different clusters. Obviously, the findings identified that the PNI series were distinctive in two groups of clusters.

As a conclusion, the clustering analysis was able to explore the homogenous areas suffered from the same streamflow droughts.

Table 2. The number of drought events at the each station.

Station	Extreme	Severe	Moderate	Slight	Total
Dehgalan	8	6	0	1	15
Hashtad Joft	6	5	3	2	16
Meher Abad	8	2	3	0	13
Shilan	12	5	3	1	21
Tunnel Chehelgazi	4	3	1	4	12
Yanlo	5	2	4	3	14

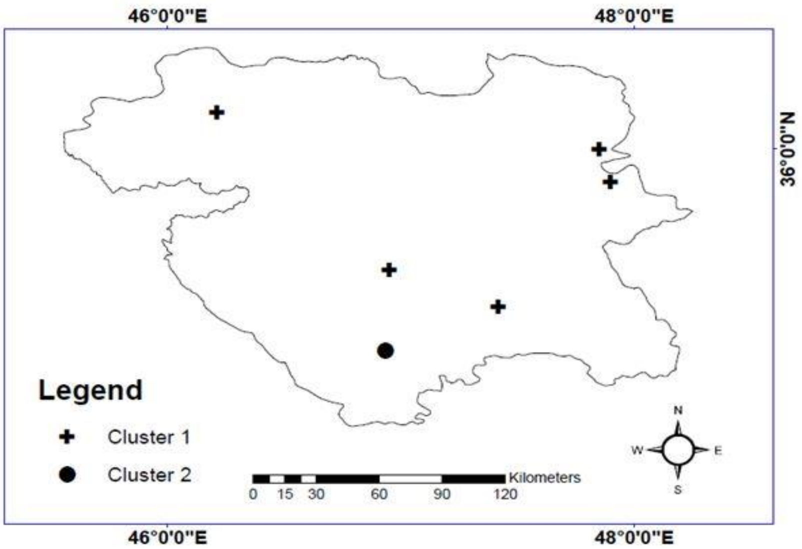

Fig. 4. Spatial distribution of different clusters in the study area.

Therefore, the results of this work showed that the study area suffered from streamflow drought events over the three last decades, especially in last 14 years with immense impacts on environment and ecosystems. The narrowing of the gap between water supply and demand and also as a direct outcome of the increase of drought duration, severity and frequency, there has been a remarkable increase in the impacts associated with drought in almost all countries over the world (Wilhite *et al.* 2014). The adaptation of ecosystems to extreme events such as drought episodes will gain much more importance under future climate change (Taeger *et al.* 2013). According to He *et al.* (2014), drought might be the most important physical stress of terrestrial ecosystems because it limits vegetation growth, increased wildfires, and induce tree mortality. Moreover, OBrien *et al.* (2013) quantified drought in terms of intensity and duration of relative dryness and determined droughts characteristics associated with poor mental health to evaluate any vulnerability in rural and urban communities. Their results indicated that during a 7-year period of major and widespread drought, one pattern of relative dryness was associated with increased distress for rural but not urban dwellers. It is possible in the studied region that the streamflow droughts cause many impacts on the natural resources and environment. So, it is necessary to investigate the comprehensive impacts of streamflow droughts.

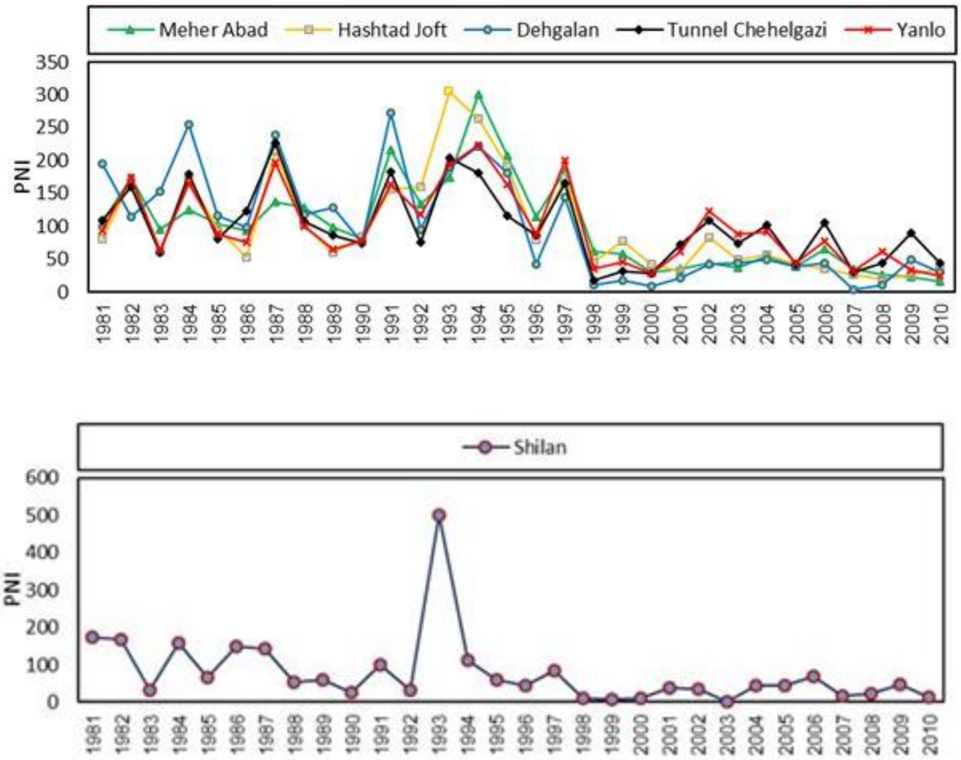

Fig. 5. The PNI series at each station classified in different clusters.

Conclusion

In this research, we analyzed the streamflow droughts based on the PNI and clustering approaches in the Kurdistan Province, Iran, over the 1981-2010. The K-S test was considered for streamflow time – series, indicating that it follows the normal distribution at the 0.05 significance level. Generally, the results showed that most of these droughts have been commenced since 1997, while in the most stations the extreme streamflow droughts occurred from 1997 through 2001. The extreme status in Shilan station had the highest number (value 12), while Tunnel Chehelgazi showed the lowest status (value 4). Meanwhile, we used hierarchical clustering in order to explore homogeneous areas suffered from streamflow droughts. Based on the dendrograms, two different clusters were selected which 5 out of 6 stations were classified in cluster 1 having the same situation in most years. Shilan station showed different behavior in comparison with other stations and classified in cluster 2. As a conclusion, the clustering analysis was able to explore homogeneity area suffering from the same streamflow droughts. Therefore, the results of this work showed that the study area suffered from streamflow drought events over the three last decades, especially in last 14 years with possible impacts on environment and ecosystems.

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ارزیابی خشکسالی های جریان رودخانه ای در استان کردستان، ایران

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چکیده

در این مقاله، خشکسالی‌های هیدرولوژیک براساس درصد شاخص‌های نرمال (PNI) و روش‌های خوشه‌بندی در استان کردستان ایران در سال‌های ۱۹۸۱ تا ۲۰۱۰ مورد تجزیه و تحلیل قرار گرفت. آزمون کولموگروف-اسمیرنوف (K-S) برای بررسی سری زمانی جریان رودخانه‌ای در نظر گرفته شد و نتایج آزمون K-S نشان داد که سری زمانی جریان از توزیع نرمال در سطح معنی دار ۰/۰۵ پیروی می‌کند. به طور کلی نتایج مشخص کرد که بیشترین خشکسالی‌های هیدرولوژیک از سال ۱۹۹۷ آغاز شده و در بیشتر ایستگاه‌ها خشکسالی‌های شدید در سال‌های ۱۹۹۷ تا ۲۰۰۱ رخ داده است. علاوه بر این، تعداد حوادث خشکسالی در هر ایستگاه نشان داد که وضعیت خشکسالی شدید در ایستگاه شیلان بالاترین مقدار با ارزش ۱۲ بود، در حالی که در ایستگاه تونل جهل قاضی پایین‌ترین وضعیت خشکسالی را با ارزش ۴ نشان داد. در همین حال، از رویکرد خوشه‌ای برای شناسایی منطقه‌های همگن که از خشکسالی هیدرولوژی متاثر می‌شوند استفاده کردیم. به این ترتیب، ۵ ایستگاه از ۶ ایستگاه در خوشه ۱ طبقه‌بندی شدند که در بسیاری از سال‌ها مشابه وضعیت دارند. ایستگاه شیلان در مقایسه با ایستگاه‌های دیگر شرایط خاصی داشت و در خوشه ۲ طبقه‌بندی شد. در نتیجه، تجزیه و تحلیل خوشه‌ای قادر به تعیین مناطق همگنی است که از خشکسالی مشابه جریان رنج می‌برند. بنابراین، این تحقیق نشان داد که منطقه مطالعاتی از وقایع خشکسالی هیدرولوژیک طی سه دهه گذشته، خصوصاً در ۱۴ سال قبل رنج می‌برد که می‌تواند منجر به تاثیرات بسیاری بر محیط زیست و اکوسیستم‌ها شود.

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